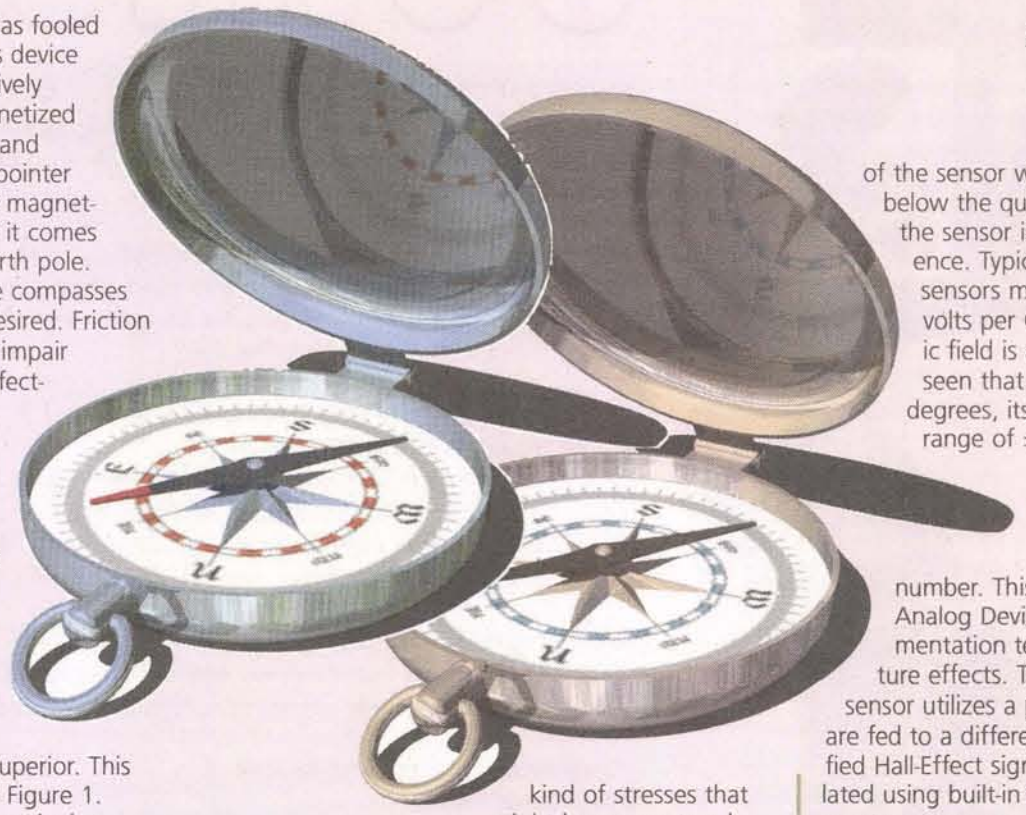
BUILD AN ELECTRONIC COMPASS

SOLID-STATE CIRCUIT · CONTAINS NO MOVING PARTS

by Anthony J. Caristi



Just about every one of us has fooled around with that ubiquitous device we call a compass. It's relatively simple, consisting of a magnetized pointer or needle balanced and suspended on a pivot. The pointer – influenced by the earth's magnetic field – is free to rotate and when it comes to rest, it points to the magnetic north pole. Although even the most inexpensive compasses really work, they leave a lot to be desired. Friction between the pointer and pivot may impair operation, they need to be held perfectly horizontal for reliable operation, and it takes some time for the pointer to come to rest at a point that we hope is true magnetic north.

The magnetic north pole of the earth is actually located in the Northwest Territories of Canada. Because of this, a magnetic compass will not point to true geographical north unless it is located near an imaginary line that stretches from the Alabama Gulf to Lake Superior. This line is identified as "zero degrees" in Figure 1.

For all other locations, one must take into account the offset – called magnetic declination – which can be as much as ±20 degrees in the United States. The map in Figure 1 can be used to determine the amount of magnetic declination for all parts of the continental United States.

Modern electronics technology has provided the means to construct a solid-state compass containing no moving parts, thus avoiding mechanical problems. The electronic compass described here is extremely easy to build, and will easily outperform the old fashioned magnetic types. It utilizes a device called a linear Hall-Effect generator which produces an electrical output that is proportional to the intensity of the magnetic field passing through the semiconductor material.

Since this compass contains no moving parts, it is extremely rugged and can tolerate virtually any kind of stresses that might be encountered when traveling in rough or mountainous terrain. It is easy to use, and will provide a quick and reliable reading. Power to operate the circuit is provided by a common nine-volt transistor radio battery that will allow many hours of intermittent operation.

HOW IT WORKS

Refer to Figure 2. A Hall-Effect sensor consists of a small sheet of semiconductor material through which a bias current flows. Its output voltage – measured perpendicularly to the flow of current – is a function of the intensity of magnetic lines of force that pass through the chip in the direction depicted in the illustration.

Depending upon the actual direction of the magnetic field and its intensity, the output voltage of the sensor will be somewhat above or below the quiescent value that exists when the sensor is not subject to magnetic influence. Typical sensitivity of many Hall-Effect sensors may be in the order of two millivolts per Gauss. Since the earth's magnetic field is about one-half Gauss, it can be seen that as the sensor is rotated 360 degrees, its output voltage may vary over a range of ± one millivolt.

Unfortunately, Hall-Effect sensors are not very temperature stable, and the output voltage will not be an absolute number. This problem has been solved by Analog Devices Corporation using instrumentation technology to reduce temperature effects. Their AD22151 magnetic field sensor utilizes a pair of Hall-Effect devices that are fed to a differential amplifier. The two amplified Hall-Effect signals are synchronously demodulated using built-in circuitry, and the result is a temperature compensated, low offset output voltage that is proportional to the intensity and direction of the external magnetic field.

ABOUT THE CIRCUIT

Refer to the schematic diagram. Nine-volt battery power is applied to U1, a fixed five-volt linear regulator. The use of a regulator is required to maintain circuit stability as the terminal voltage of the battery decreases with use. A spring loaded switch applies voltage to the circuit so that once a reading is taken, the power will automatically disconnect when the user releases the switch.

U2 is a surface mount linear output magnetic field sensor that produces an output voltage which is proportional to a magnetic field that is applied perpendicularly to the top surface of the package.

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The chip contains a built-in op-amp that utilizes external resistors (R2 and R3) to set the gain of the device. Using the values shown in the schematic, the sensitivity of U2 is about 1.3 millivolts per Gauss. U3 is a combination op-amp and comparator chip that is used to amplify the output voltage of the magnetic sensor, and detect when it exceeds a certain value as set by potentiometer R7.

U3A is the op-amp section of the chip and has a gain of 470 as determined by R4 and R5. It has a large value of capacitance across the feedback resistor to filter out any AC signals generated by the demodulator in the magnetic sensor. The op-amp output voltage at pin 1 is fed to the positive input of comparator U3B, pin 5. Potentiometer R7 is set during calibration so that the voltage at the wiper is somewhere between the maximum and minimum output voltage at pin 1 of U3A as the compass is rotated a full 360 degrees.

Thus, it can be seen that the output voltage of the comparator at pin 7 will be high when the compass is facing magnetic north, and low when it is facing 180 degrees away from magnetic north. When R7 is properly set, the high level output of U3B will represent a smaller rotational arc (such as 90 degrees or less) than that for U3B low level output.

When the comparator output is high, Q1 is forward biased, illuminating LED1. In use, the compass is rotated to identify the arc at which the LED is illuminated. Then, the North Pole indicator is positioned at the center of the arc. The scale of the compass will then indicate all compass directions.

CONSTRUCTION

The compass is constructed on a small single-sided printed circuit board measuring about 3/4 by 2-1/4 inches. This allows it to be installed vertically in a small, square enclosure less than one inch high. The circuit is not critical, and may be wired on a perfboard, if desired. If you do not wish to etch and drill your own board, one may be purchased from the source listed in the parts list. Figure 3 illustrates the printed layout, shown in full size as seen from the copper side of the board.

The enclosure will also contain the nine-volt battery and the on/off push-button switch. At final assembly, LED1 will be mounted to the top surface of the enclosure, at the north indicator of the scale (Figure 7).

Figure 4 illustrates the parts placement. The first components that should be assembled to the board are U2 and U3. These are surface mount components that must be properly soldered in place, with a low wattage soldering iron, that has a pointed tip. As indicated in the printed layout of Figure 3, pin 1 of each IC pattern is represented by a dot. Figure 5 shows how to identify the corresponding pin #1 of each of these two parts. Use the following procedure to solder the chips to the board:

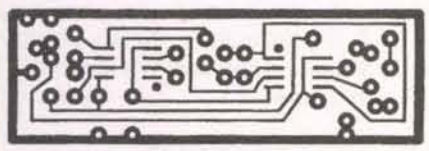


FIGURE 3.

Printed layout shown full size as seen from the copper side of the board.

1. Gently clean the board with a scouring pad to remove oxidation and any other contaminants. Rinse well in cold water and dry thoroughly.

2. An assistant will be helpful with this and the next step. Place the IC directly over the copper pattern, observing where pin 1 of the chip is. Some ICs have a small dot that indicates pin 1. Others indicate pin 1 by the legend that identifies the part number. See Figure 5.

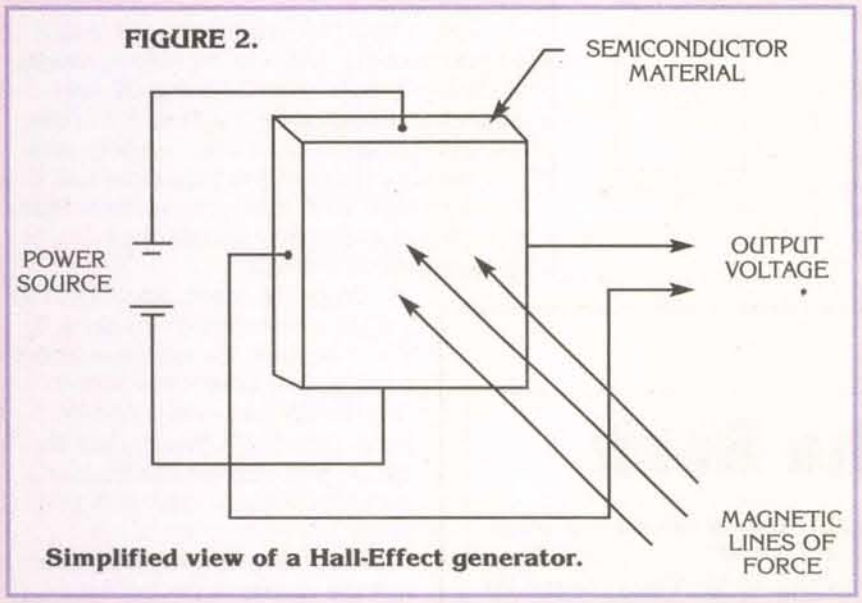
3. While holding the chip in place, solder only one corner pin to the board being careful not to use excessive heat or solder. Too much heat will cause the copper pad to lift off the board. Excessive solder may result in a short circuit between two adjacent pins.

4. Examine the location of all pins of the chip with respect to the copper pattern. All pins must lie directly over the pads. If not, adjust the chip's position or remove the IC and repeat steps 2 and 3.

5. If you are satisfied that all pins are properly positioned, solder the remaining seven in place. When finished, examine the connections to be sure they are solid with no solder bridges between pins.

Insert the remaining components into the board as illustrated in Figure 4, using Figure 6 to identify the connections of the terminal connections of Q1 and U1. Pay strict attention to the orientation of these parts and the electrolytic capacitor, which are polarized. Double check before soldering – any polarized component placed backwards in the circuit will cause an inoperative compass and possible damage to one or more of the parts.

FIGURE 2.



Simplified view of a Hall-Effect generator.

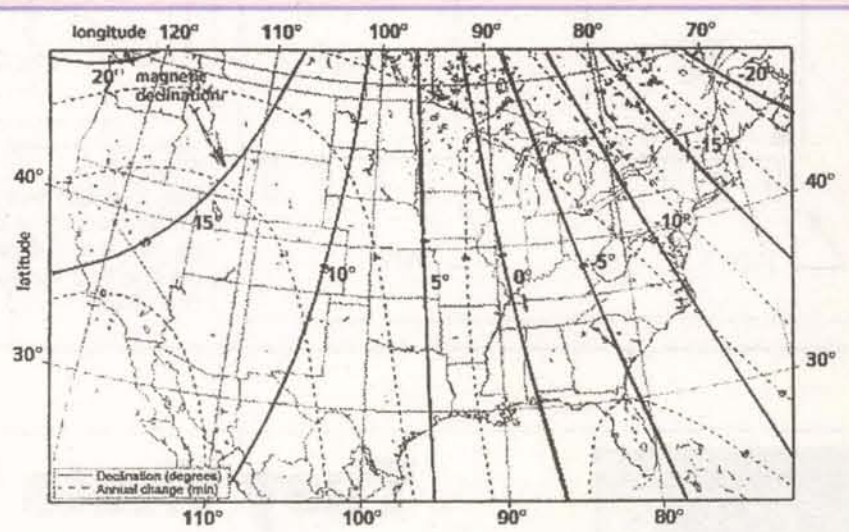


FIGURE 1. Positive value of magnetic declination indicate that True North lies west of the magnetic North Pole. Negative values indicate that True North lies east of magnetic north.

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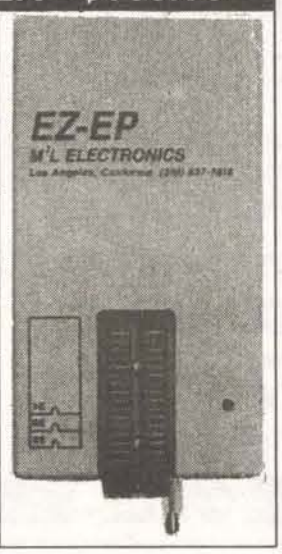

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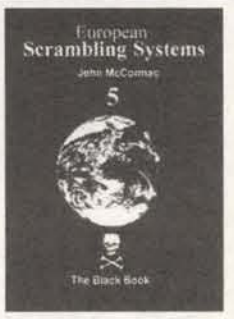

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The board requires one jumper wire, identified as J1 in Figure 4, to complete the circuit. This wire connects U2 and U3 pin 4 to circuit common. The LED may be temporarily soldered to the board, as indicated in the schematic diagram, for the preliminary test. Be sure to observe polarity of this component, which can be determined by using an ohmmeter that is set to one of the higher Ohms scales.

When finished stuffing the board, check for inadvertent short circuits and bad solder connections. Any connection which is not shiny and smooth is suspect and should be redone by removing the old solder with braid, cleaning the joint, and applying new solder. Correct any problems now before proceeding.

BATTERY CONNECTOR

Nine-volt battery clips are readily available from electronics parts suppliers, but one is easily fabricated by taking apart an old battery and removing the connector. It is best to solder a red and black flexible wire to the rear side of the connector, observing proper polarity which will be opposite to that of a battery. Be sure to check connector wiring by clipping on a fresh battery and verifying with a DC voltmeter that the red wire is positive and the black wire is negative.

Once the polarity of the connector wiring has been verified, remove the battery and temporarily solder the two wires to the board at the +9 volt and common circuit connections as indicated in Figure 4 and the schematic diagram. When finished, set the board aside while preparing the enclosure.

ENCLOSURE

Select a suitable enclosure – plastic and not metal – that is about 2-1/2 inches square so that it will accommodate the scale illustrated in Figure 7. Make a photocopy, lay it on the top side of the enclosure, and mark the location of the LED which should be on the north pointer of the scale. Drill a suitably-sized hole in the enclosure for the LED.

Place the PC board in a vertical position inside the enclosure, against the side that will correspond with the location of the LED and north pole indicator of the scale. U2 and U3 should be facing the outside, and potentiometer R7 should be on the right as seen from the top. Note the location of potentiometer R7, and drill a hole in the side of the enclosure that will permit a small screwdriver to be used for calibration. Determine a suitable location for the on/off switch, and drill a hole for that component.

Proceed to the preliminary checkout before permanently mounting the board and other parts to the enclosure.

PRELIMINARY CHECKOUT

Take a fresh nine-volt battery and snap it on the connector. Measure the output voltage of the regulator (across C2) with a DC voltmeter. Normal indication is 4.75 to 5.25 volts. If you do not obtain the correct reading, measure the battery terminal voltage to be sure it is at least eight volts. If so, remove the battery from the circuit and troubleshoot the board to locate and repair the fault.

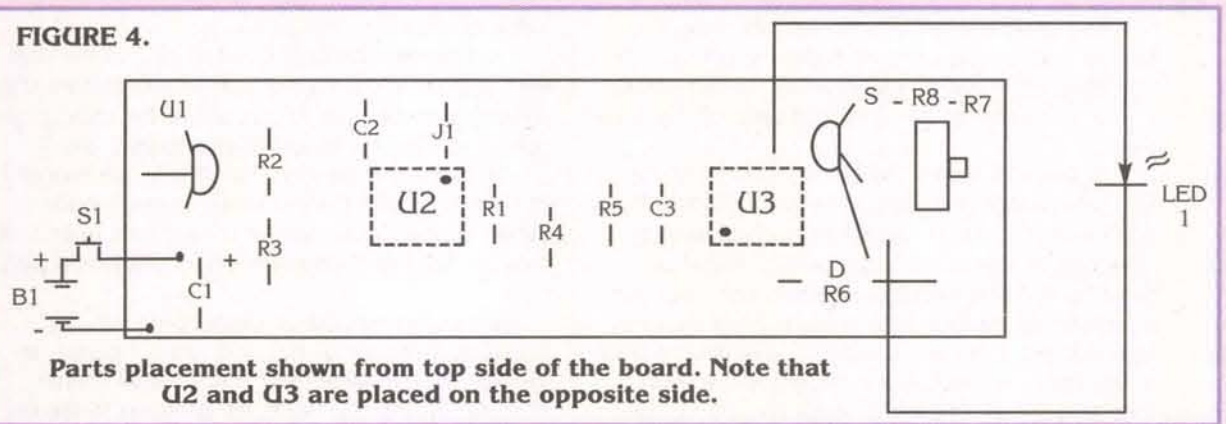
Check the orientation of U1, U2, and U3 as illustrated in Figures 4, 5, and 6. Measure the resistance across C2 to be sure there is no short circuit. Normal indication is 2.5K or more. Try a new regulator chip. Do not proceed with the checkout until the fault has been repaired and U1 delivers five volts to the circuit.

Continuing with the test, measure the voltage at pin 1 of U2. Normal indication is 2.5 to 4.5 volts. Rotate R7 over its range and verify that the LED will be lit at one part of the rotation, and extinguished for the remainder.

Hold the board in the vertical plane so that the long dimension is horizontal with the surface mounted components facing away from you, just as it would be when mounted in the enclosure. Turn your body so that the surface mounted components face north, and carefully adjust R7 so that the LED just comes on. Allow time for the long time constant of the amplifier to stabilize.

Now turn yourself and the board around slowly and note that the LED will be off when the chips on the board face south, and on when they face north. This completes the preliminary checkout.

FIGURE 4.



Parts placement shown from top side of the board. Note that U2 and U3 are placed on the opposite side.

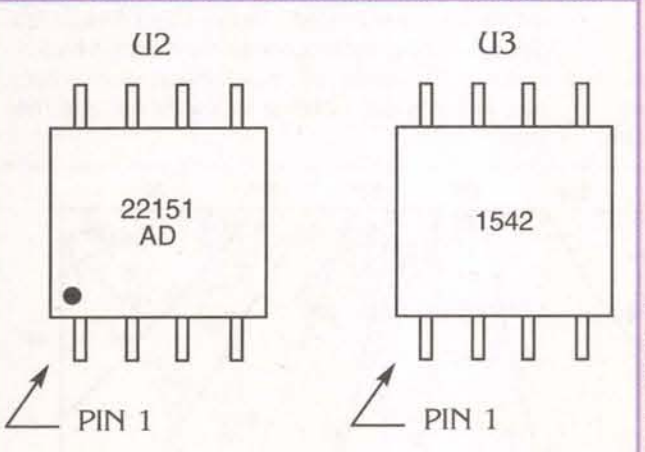


FIGURE 5.
Pin 1 of U2 and U3 is identified by a dot, or by the legend printed on the top surface of the chip.

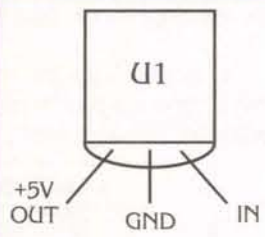
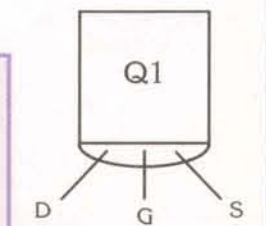


FIGURE 6.

Terminal identification of U1 and Q1.



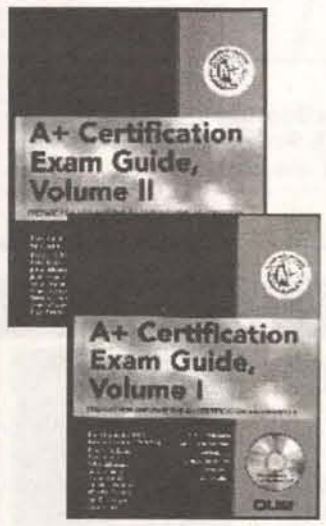


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FIGURE 7.

Use a photocopy of this artwork for the scale. Glue it in place on the top of the enclosure.

FINAL ASSEMBLY

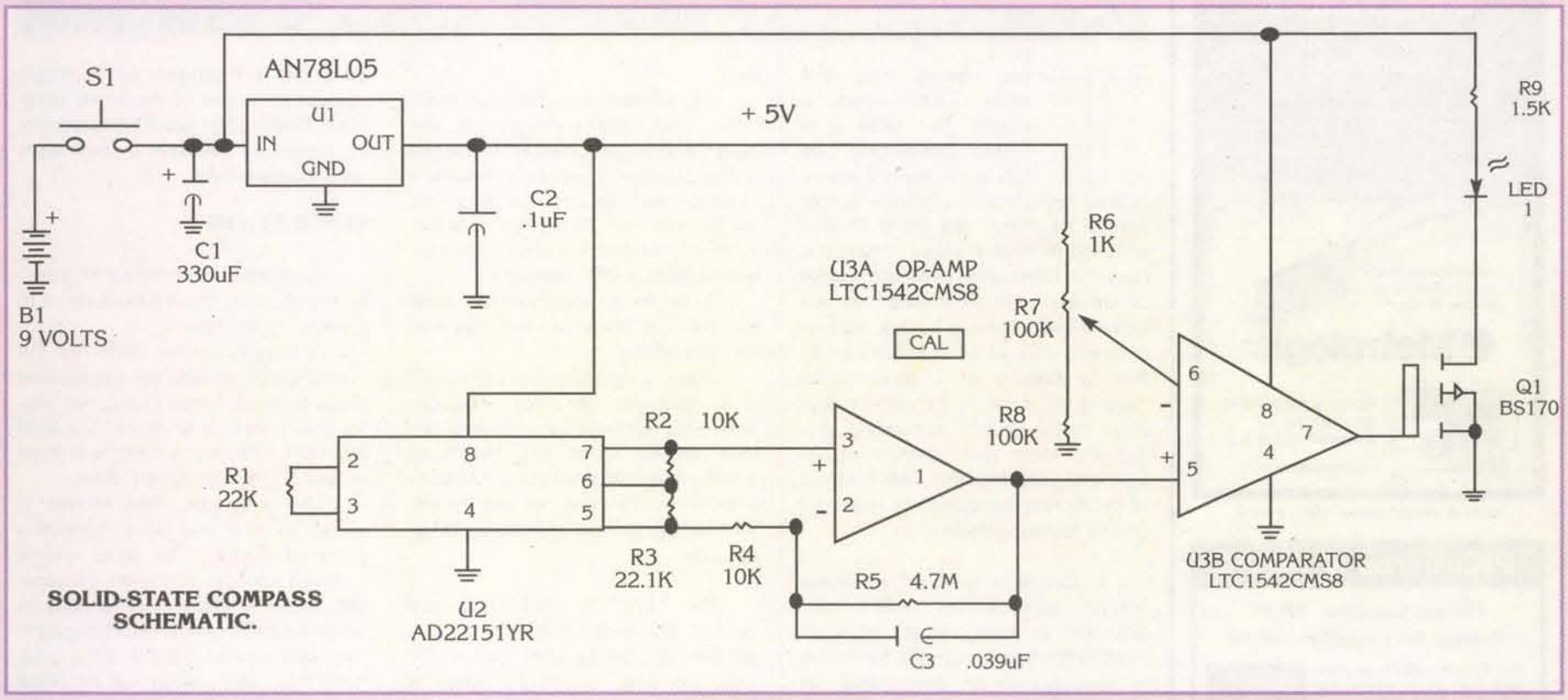
The LED may be removed from the board and mounted to the top of the enclosure through a hole, using RTV silicone rubber. After the adhesive has cured, a pair of small gauge flexible wires may be soldered to the LED. Use two different colors and check the polarity of the connections with an ohmmeter so that the wires will be properly connected to the circuit.

The easiest way to mount the PC board to the side of the enclosure is to use a small amount of RTV silicone rubber, but the builder has the option of using any other method that he or she finds suitable. The board must be mounted in the vertical plane against the side of the enclosure that corresponds to the LED and north indicator of the scale, with the surface mounted components facing to the outside. Mount the on/off switch, and hold the power switch.

Rotate the compass very slowly in a horizontal circle and note the arc at which the LED is lit. Carefully adjust R7 with a small screwdriver so that the arc is as small as possible when facing magnetic north, consistent with a solid lighting of the LED. An arc of 45 degrees is ideal.

Note the position of the compass as the LED comes on from the left and from the right. True magnetic north will be that position of the compass when the LED is placed at the center of its lighted arc. Use the information in Figure 1 to offset the compass for the number of degrees that correspond with your location.

Once the compass is oriented to that position, all directions will be indicated by the scale. **NV**



SOLID-STATE COMPASS SCHEMATIC.

Note: The values of R6 and R8 may optionally be tailored to center the adjustment range of R7 for the particular U2 chip used in the circuit.

TROUBLESHOOTING

If you do not obtain the results described above, remove power from the board and visually check for opens, shorts, and bad solder connections. Refer to Figure 4 and the schematic diagram and check that all components are the correct values and placed in their respective locations. Verify that U2 and U3 are oriented properly. Check the polarity of the LED. If necessary, try a new LED.

wire it and the battery connector in accordance with the schematic diagram. Be sure to observe proper polarity. Secure all wiring away from the magnetic sensor.

FINAL ADJUSTMENT

Final adjustment of R7 should be made outdoors, away from buildings or metal structures which may distort the earth's magnetic field. Insert a fresh battery into the connector and put the cover in place. Hold the enclosure horizontally with the LED positioned away from you, press and

PARTS LIST

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C3: 0.039 uFd 50-volt ceramic disc capacitor
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R2: 10K 1/4-watt 1% metal film resistor
R3: 22.1K 1/4-watt 1% metal film resistor
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R5: 4.7 Megohm 1/4-watt carbon resistor
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R9: 1.5K 1/4-watt carbon resistor
LED1: High-efficiency light emitting diode, Digi-Key 1700QT-ND or similar
Q1: N channel MOSFET, BS170 or similar
U1: 5-volt linear regulator, AN78L05 (Digi-Key)
U2: Magnetic sensor, Analog Devices AD22151YR (Future Electronics)
U3: Op-amp/comparator, Linear Technology LTC1542CS8-ND (Digi-Key)
S1: Push-button switch, Digi-Key 150C-ND or similar
Misc: Enclosure, battery clip, hook-up wire

SOURCES OF SUPPLY

Digi-Key: 1-800-344-4536

Future Electronics (AD22151YR): 1-800-333-9943

Note: The following parts are available from A. Caristi, 69 White Pond Road, Waldwick, NJ 07463: Etched and drilled PC board @ $9.95, U1 @ $2.00, U2 @ $9.75, U3 @ $6.75, set of four metal film resistors @ $2.00, Q1 @ $3.00. Please add $5.00 postage/handling.

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